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Dr. H. Nachman	(202) 767-4939	AFOSR/ NM

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CERTIFICATION

The Contractor, PK Corporation, hereby certifies that,
to the best of its knowledge and belief, the technical
data delivered herewith under Contract F49620-87-C-0107
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To PK Corporation
PI: Dr. P. Papantoni-Kazakos

Title: Random Access Transmission Algorithms for
Data Local Area Networks (unclassified)

SUMMARY OF ACCOMPLISHMENTS
(September 15, 1987 to September 15, 1989)

The objective of this research is to address some of the fundamental issues that arise in the modeling, analysis and design of interconnected wire and radio Local Area Networks (LANs).

In the case of wire LANs, the individual LANs are interconnected through store-and-forward devices, which relay packets between adjacent LANs and route them to their final destination. In radio networks, we are concerned with multi-hop packet radio networks that consist of a collection of interconnected local clusters; a local cluster is a single-hop network in which the (possibly mobile) users are within transmission range of each other. The local cluster interconnection is provided by relay nodes that belong to the intersection of two or more local clusters, or by special "bridge nodes" if local clusters are disjoint.

The focus of the research is on the mutual impact of interconnection and access protocols, possible network architectures for interconnecting devices and backbone networks, routing policies, and flow and network-access control for congestion prevention and performance optimization.

In accordance with the research objectives, the following research problems have been formulated and addressed during the period of the contract:

1. LAN Interconnection

    1.1. Interconnection of CSMA/CD and CSMA LANs via Bridges

    1.2. Interconnection of Token-ring LANs via Bridges

2. Interconnection of Single-hop Random Access Networks

3. Multi-LAN Interconnection via dynamically adaptive transmissions

4. Multiplexing of low and high priority data per LAN.

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In the sequel, we give a brief outline of each of the above projects and the research accomplishments.

1. LAN Interconnection

This project is concerned with performance evaluation and protocol design in extended LANs. Extended LANs consist of a number of single LANs interconnected via store-and-forward interconnecting devices, such as bridge (MAC relays) or routers (Network layer relays); also, some of the LANs might be connected via gateways to Wide Area Network (WAN) links.

The questions addressed in this project include the following: Given the topology, individual LAN characteristics (type, MAC, Logical Link Control (LLC), input traffic statistics), inter-network traffic requirements, access and routing policies at the bridges, what is the (global and local) throughput-delay performance of the extended LAN? What is the effect of the internetwork traffic on the intranetwork traffic in an individual LAN? Is the bandwidth allocation (as induced by the used protocols) fair to internetwork and intranetwork traffic? How should the standard LLC and MAC protocols, which were designed for individual LANs, be enhanced by appropriate dynamic retransmission control and flow-control mechanisms to effectively prevent severe performance degradation due to congestion? To what extent the bridge processing time, access policy, and buffer sizes affect performance? Is it possible to improve the performance of a single LAN by partitioning it into a number of interconnected sub-LANs? How do different LAN interconnection topologies (mesh, hierarchical, series, star) compare to each other in terms of performance? How do the processing time, speed mismatch, buffer size of a LAN-WAN gateway affect performance?

Progress to Date:

1.1. Interconnection of CSMA/CD and CSMA LANs via Bridges

We have investigated simple topologies (series and star) of bridged CSMA/CD and CSMA LANs. The research methodology has been based on a synergism of queueing analysis and simulations.

Regarding queueing analysis, our approach has been based on decomposition and renewal coupling approximations: all non-renewal arrival and departure processes involved in the coupling between subsystems (e.g., single LANs, bridge queues) are approximated by consistent renewal processes. A simulator at the MAC layer has been developed.

For the multiplexing of the internetwork and intranetwork traffic two policies have been considered: frequency division multiplexing (FDM) and contention multiplexing (CM). The throughput-delay performance evaluation of these two policies for a basic two-LAN system model revealed the following:

(a) The throughput performance of the interconnected system under the FDM policy is superior to that under any CM policy. However, for properly designed CM policies, this difference can be made quite small.

(b) CM policies provide better delay performance than FDM policies under light (and in some cases moderate) internetwork traffic conditions.

(c) CM policies have an overwhelming advantage over FDM policies in that they can be implemented without software or hardware modification in the interconnected LANs, and in a manner transparent to the network users.

The CM policy has been further investigated in the context of a multi-LAN system consisting of N CSMA/CD LANs interconnected via an N-port bridge. The performance of the interconnected system with or without bridge priority has been evaluated using the decomposition queueing analysis method and simulations. Finally, the bridge interconnected system has been compared to a system in which the bridge is replaced by a repeater, and the performance advantages of the former system over the latter have been quantified.

Work has been accomplished on interconnected CSM∕ and CSMA/CD LAN systems with arbitrary topologies, in which the bridges implement the "spanning tree" routing protocol (IEEE 802.1 MAC Bridge Standard).

1.2. Interconnection of Token-Ring LANS

Although this research focuses on CSMA LANs, we have also investigated token-ring LANs because of the following reasons: 1) these two LAN types already co-exist in most large LAN installations, and 2) token-ring LANs can be used as high-speed backbone networks for the interconnection of smaller CSMA/CD LANs.

We have investigated a basic two-ring system in which both the ring stations and the bridge operate under exhaustive service. Using the decomposition analysis approach, we have obtained simple formulas for the mean delay that a packet experiences at a ring station and at the bridge. Finally, we have compared the mean packet delay in a single ring to that obtained by splitting the ring into two bridged sub-rings, and we have found that splitting can improve performance, provided that the fraction of the internetwork traffic is below a threshold value, which increases with the total input traffic.

Work has begun on a system that interconnects CSMA/CD and token-ring LANs via a high-speed token-ring backbone network.

Documentation

[1] L. Merakos and G. Exley, "Interconnection of Two CSMA LANs using a Bridge: Transmission Policies and Performance," Technical Report to AFOSR.

[2] L. Merakos and H. Xie, "Interconnection of CSMA/CD LANs via an N-port Bridge," Technical Report to AFOSR; submitted for presentation at the 1989 IEEE International Communications Conference, Boston, MA, June 1989 and for publication at the IEEE Trans. on Communications. To appear in the Proceedings of the IEEE INFOCOM'88 Conference, Ottawa, Canada, April 1989.

[3] C. Bisdikian, T.-M. Tsai and L. Merakos, "Approximate Mean Delay Analysis for Interconnected Token-ring LANs," Technical Report to AFOSR; to appear in the Proceedings of the 1988 COMCON Conference, Advances in Communications and Control Systems, Baton Rouge, LA, Oct. 1988.

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2. Interconnection of Single-hop Random Access Networks

Network interconnection becomes a necessity whenever full connectivity of geographically separated networks is desired. Here we consider the interconnection of two single-hop packet radio networks, each of which is assumed to connect a large population of bursty users via a random access broadcast channel. The interconnection is provided by a full duplex bridge link that connects two bridge nodes, one in each network. The bridge nodes store-and-forward internetwork packets from the source network to the destination network. Due to the internetwork traffic, which presents an additional load to each of the broadcast channels, the throughput-delay performance of a network in the interconnected system will be worse than that of the same network when it operates isolated. This issue raises the following questions that we have addressed in this study: how much does performance deteriorate for a given bridge channel access policy and a specified amount of internetwork traffic?

Progress to Date:

We have considered the following simple bridge transmissions policy for synchronous channels: at the beginning of each slot, bridge node i transmits a packet (if it has any) with probability π_i. If the packet collides with a local packet, the packet is retransmitted in the next slot with the same probability.

Given the random access protocols used for local transmissions, and the amount of internetwork traffic, we have determined the total amount of traffic that the interconnected system can accommodate before the local networks or the bridge node queues reach their capacity.

Work has begun on the packet delay characteristics of the interconnected system.

Documentation

C. Bisdikian and L. Merakos, "On the Capacity of Interconnected Single-hop Random Access Networks", Technical Report to AFOSR.

3. Multi-LAN Interconnection via Dynamically Adaptive Transmissions

In mobile topologies, the LAN configurations are time varying. System connectivity is then accomplished via the transmission of topological and system state data by a portion of the users. Such transmissions are accommodated by the existing transmission channels, and their multiplexing with the regular user traffic is an important issue, for system stability and delay control, where priority on delay control should be given to the data which carry topological and system state information.

Progress to Date

We considered LAN interconnections via adaptive and dynamic transmissions from part of the user population. Along these lines, we initially considered a two-LAN system with packet transmitting users. We assumed that each LAN deploys a limited sensing random access algorithm and contains local users who transmit their packets only via the algorithm in their own LAN. The system also contains marginal users, who may transmit their packets via either one of the algorithms in the two LANs.

For the above two-LAN system, we adopted a limited sensing random access algorithm per LAN that has been previously studied. This algorithm utilizes binary, collision versus noncollision, feedback per slot, and in the presence of the limit Poisson user model and the absence of marginal users its throughput is 0.43. We considered a dynamic interconnection policy for the marginal users, and we then studied the overall system performance in the presence of limit Poisson user populations. Specifically, we studied the stability regions of the system and the per packet expected delays. Our interconnection policy accelerates the marginal users, presenting them with a significant delay advantage over the local users. This is desirable when the marginal users transmit either high priority data or topological system information. The main results of this research are as follows:

(a) Dynamic interconnection policies are feasible, they require no a priori topological or user population information, they induce very good throughput-delay performance, and they are recommended for the accommodation of users who transmit either high priority data or topological information.

(b) Methodologies for stability (throughput) evaluation and delay analysis were devised in the process, which easily generalize to multi-LAN interconnections.

We are presently investigating the extension of this type of interconnection to multi-LAN topologies.

Documentation

Papantoni-Kazakos, P, M. Paterakis, and Liu Ming, "Interconnection Algorithms in Multi-Hop Packet Radio Topologies," submitted to the IEEE Transactions on Information Theory; Technical Report to AFOSR.

Delic, H., and Papantoni-Kazakos, P., "Performance Analysis for Multi-Channel Random Access Interconnection Algorithms," submitted to the IEEE Transactions on Communications; Technical Report to AFOSR.

Papantoni-Kazakos, P., Paterakis, M., and Liu Ming, "Interconnection Algorithms in Mobile C3 Topologies," JDL C3 Research Symposium, June 1988.

P. Papantoni-Kazakos, "Interconnection Algorithms in Multi-Hop Packet Radio Topologies", IEEE PCCC-9 Phoenix, Arizona, March 1989.

Delic. H., and Papantoni-Kazakos, P., "Performance Analysis for Multi-Channel Random Access Interconnection Algorithms," Conference on Information Sciences and Systems, Johns Hopkins Univ., March 1989.

4. Multiplexing of Low and High Priority Data per LAN

Single LANs frequently generate mixed traffic: Low and High priority. For economy in bandwidth, both traffic categories are accommodated by a single common channel. The multiplexing of the mixed traffic is an important issue, since there is frequently a strict upper bound on the delays of the high priority traffic, and since it is desirable that the delays of the low priority traffic are controlled as well.

Progress to Date

We considered LANs with mixed traffic: high and low priority. (1) For such LANs and finite number of users who may generate high priority data, we proposed and analyzed an algorithm with mixed characteristics: Dynamic tree search, for the high priority data, and random access, for the low priority data. The algorithm attains high throughputs and guarantees an upper bound on the per high priority packet delay. For the limit Poisson user model regarding the low priority traffic, (worst case), the algorithm attains good expected per low priority packet delays. The algorithm is limited sensing: It only requires that each user monitor the channel feedback from the time he generates a packet to the time that this packet is successfully transmitted. (2) We considered LANs such that the high priority users are mobile and their population and identities are ill specified. For such LANs, carrying also low priority traffic, we developed and analyzed a mixed random access algorithm with the following characteristics: All the traffic is maintained, and the delays of the high priority traffic remain low and practically unaffected by changes in the overall traffic rates.

Documentation

P. Papantoni-Kazakos, "Multiple Access Algorithms for a System with Mixed Traffic: High and Low Priority," Technical Report to AFOSR; submitted to the IEEE Transactions on Communications.

Liu Ming, and Papantoni-Kazakos, P., "A Random Access Algorithm for Data Networks Carrying High

Priority Traffic," Technical Report to AFOSR; submitted to the IEEE Transactions on Communications.

Liu Ming, and Papantoni-Kazakos, P., "A Random Access Algorithm for Data Networks Carrying High Priority Traffic," 1989 Symposium on Command and Control Research, Washington, D.C., June 1989.

5. Competitive Processing at Central Nodes of LANs

We considered LANs carrying high and low priority traffic. We focused on the processing of the mixed traffic by the central node in the system. We modelled the mixed traffic as two independent traffic streams whose arrivals are stored in an infinite capacity buffer. The two arrival traffics are modelled as renewal processes, and are competing for service by a single processor, where one of the processes (high priority) requires a strict upper bound on the total delay per arrival. Given the above model, we found and analyzed the optimal processing policy, which attains throughput one and minimizes the delays of both the traffic streams.

Documentation

Delic, H., and Papantoni-Kazakos, P., "An Optimal Policy for Competitive Processing between High and Low Priority Arrivals," ICC'90, accepted; Technical Report to AFOSR in progress.